

water. The Detroit River is open. In Lake Erie the ice fields cover the western and eastern portions, but these fields are not heavy or extensive. In Lake Ontario the ice fields have not been visible to any extent during the winter. Many harbors are reported open on all the lakes.

In comparison with the same period last season there is much less ice reported in all of the lakes. At the Straits of Mackinac the same conditions prevail as last season except that the ice fields are not as extensive in Lake Michigan.

STUDIES ON THE VORTICES IN THE ATMOSPHERE OF THE EARTH.

By Prof. FRANK H. BIGELOW. Dated Washington, D. C., March 16, 1908.

VI.—THE ASYMMETRIC LAND CYCLONE AND ITS SYSTEM OF VORTEX LINES. THE CONCAVE DUMB-BELL-SHAPED VORTEX.

THE METEOROLOGICAL DATA.

It is necessary to construct a typical composite vortex, reduced to circular isobars, for the discussion of the system of vortex lines which will produce the circulation observed in the land cyclones of the United States. For this purpose the data for the nine typical cyclones in the accompanying list have been brought together, and their common properties united in the following manner. The cyclones are those of March 16, 1876; March 27, 1880; April 18, 1880; January 12, 1890; December 3, 1891; November 17, 1892; April 20, 1893; January 25, 1895; November 22, 1898. These were selected as having the center located near the middle Ohio Valley, and being approximately of the same dimensions. This insures the temperature distribution having a simple type, the warm air flowing from the south and the cold air from the north, while the normal isotherms are nearly parallel to the east and west lines. At the same time the isobars are nearly circular or broadly elliptical, and the wind vectors are but little distorted by local conditions, so that the composite cyclone will be a fair example for study.

The radii σ .—The construction of the isobar system is chiefly concerned with determining the proper spacing of the successive isobaric circles, and the treatment is illustrated by the cyclone of March 16, 1876. The diameter of every isobar was measured in millimeters in the northwest to southeast and the southwest to northeast directions, and the sum divided by four is the mean radius σ . The successive differences $\Delta\sigma$ for every tenth of an inch were found, and the mean taken for the nine selected cyclones.

TABLE 75.—The mean radii σ and differences $\Delta\sigma$ for the cyclone, March 16, 1876.

Isobars.	Measured diameters.			Mean radii.	
	NW-SE.	SW-NE.	Sum.	σ	$\Delta\sigma$
<i>Inches.</i>					
30.00	300	220	520	130	17
29.90	267	186	453	113	15
29.80	240	150	390	98	11
29.70	218	130	348	87	14
29.60	190	102	292	73	12
29.50	158	85	243	61	11
29.40	128	71	199	50	13
29.30	90	57	147	37	10
29.20	62	45	107	27	7
29.10	48	33	81	20	11
29.00	22	15	37	9	

Table 75 contains the measured diameters in two directions at right angles to each other, toward the northwest and

northeast respectively, the sum, the mean radius σ , and the differences $\Delta\sigma$ for the cyclone, March 16, 1876. Table 76 contains the values of $\Delta\sigma$ for nine cyclones, similarly located and developed, the mean $\Delta\sigma$ and the adjusted $\Delta\sigma$ found by a graphical construction. Table 77 gives the adopted value of the radius for each tenth-inch of pressure, assuming $\sigma = 140.5$ millimeters for the isobar 30.00 inches. These are reduced by interpolation for every 5 millimeters of pressure from 760 millimeters to 735 millimeters. Then are given the $\log \sigma$ and $\log \rho = \log \sigma_n - \log \sigma_{n+1}$, and finally σ in meters, taking 1 millimeter on the Weather Bureau Map equivalent to 10,000 meters on the surface of the ground in the United States. It will be carefully observed that the values of $\log \rho$ instead of being constant, as in the tornado, hurricane, and in a part of the ocean cyclone, are progressive from 0.10791 to 0.43573, and this proves that the land cyclone has departed seriously from the perfect dumb-bell vortex type, which was found to be applicable to the other vortices in the atmosphere.

TABLE 76.—The mean and adjusted $\Delta\sigma$ from the nine selected cyclones.

Isobars.		Mar. 16, 1876.	Mar. 27, 1880.	Apr. 18, 1880.	Jan. 12, 1890.	Dec. 3, 1891.	Nov. 17, 1892.	Apr. 20, 1893.	Jan. 25, 1895.	Nov. 22, 1898.	Mean $\Delta\sigma$	Adjusted $\Delta\sigma$
<i>Mm.</i>	<i>Inches.</i>											
762.0	30.00	17	20	21	12	18	20	22	16	14	17.8	17.0
759.5	29.90	15	15	13	11	16	18	12	18	11	14.3	15.7
756.9	29.80	11	13	15	15	17	15	19	17	14	15.1	14.5
751.4	29.70	14	14	15	13	11	8	15	19	14	13.7	13.4
751.8	29.60	12	10	15	12	11	9	10	12	19	12.2	12.4
749.3	29.50	11	14	12	11	11	11	8	9	10	10.8	11.4
746.8	29.40	13	8	11	8	9	9	9	11	.....	9.6	10.6
744.2	29.30	10	9	8	.....	15	9	6	11	.....	9.7	10.0
741.7	29.20	7	10	9	.....	15	10	10	.....	.....	10.2	10.0
739.1	29.10	11	11	13	.....	.....	.....	6	.....	.....	10.3	10.1
736.6	29.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE 77.—Computation of $\log \rho$ for the land cyclones and the distance of the isobars from the center.

<i>B</i>	σ	Isobars.		σ	$\log \sigma$	$\log \rho$	σ
<i>Inches.</i>	<i>Mm.</i>	<i>Inches.</i>	<i>Mm.</i>	<i>Mm.</i>			<i>Meters.</i>
30.00	140.5	29.92	760	125.0	2.00691	0.10791	1250000
29.90	123.5	29.72	755	97.5	1.98900	0.12390	975000
29.80	107.8	29.54	750	73.3	1.86510	0.15924	733000
29.70	93.3	29.33	715	50.8	1.70586	0.22874	508000
29.60	79.9	29.13	740	30.0	1.47712	0.43573	300000
29.50	67.5	28.94	735	11.0	1.04139		110000
29.40	56.1						
29.30	45.5						
29.20	35.5						
29.10	25.5						
29.00	15.4						
28.90	5.0						

The wind velocities, angles, and the temperatures.—The discussion of the wind velocities, the angle i that the wind vector makes with the tangent to the isobars, and the temperatures, has been carried on in the same way for these three quantities. From the center twelve radii were drawn across the isobars 30.00 to 29.00 inches, the radii being located as follows:

1. S.
2. S. 30° E.
3. S. 60° E.
4. E.
5. E. 30° N.
6. E. 60° N.
7. N.
8. N. 30° W.
9. N. 60° W.
10. W.
11. W. 30° S.
12. W. 60° S.

At the intersection of these radii with the isobars the wind velocity was scaled from the data on the manuscript chart and collected in Table 78, the angle i in Table 79, and the temperature t in Table 80. Examples of these data are given for the cyclone of March 16, 1876. The next step was to collect the same elements together at each point for the nine cyclones, and take out the mean values.

TABLE 78. — *The wind velocities in miles per hour for March 16, 1876.*

	30.00	29.90	29.80	29.70	29.60	29.50	29.40	29.30	29.20	29.10	29.00
S.....	10	10	12	14	28	54	42	20	14	.....	.....
S. 30° E.....	12	10	18	20	20	16	20	16	18	.....	.....
S. 60° E.....	10	26	40	40	20	12	14	24	16	.....	.....
E.....	12	20	24	24	16	10	14	8	10	.....	.....
E. 30° N.....	20	24	26	18	18	20	22	10	12	.....	.....
E. 60° N.....	.....	.....	18	24	28	20	26	12	12	.....	.....
N.....	.....	.....	24	24	24	24	24	20	14	.....	.....
N. 30° W.....	18	30	32	36	30	24	24	18	20	.....	.....
N. 60° W.....	28	30	36	36	30	24	24	16	16	.....	.....
W.....	24	28	28	26	24	21	19	14	16	.....	.....
W. 30° S.....	8	12	20	24	28	28	26	22	19	.....	.....
W. 60° S.....	6	14	20	24	36	34	24	20	20	.....	.....

TABLE 79. — *The angle —i for March 16, 1876.*

	30.00	29.90	29.80	29.70	29.60	29.50	29.40	29.30	29.20	29.10	29.00
S.....	40	35	40	45	50	50	55	55	55	56	60
S. 30° E.....	42	48	45	50	40	40	45	30	30	25	20
S. 60° E.....	30	40	30	25	25	20	40	45	35	20	25
E.....	25	25	30	30	30	35	30	30	25	25	20
E. 30° N.....	90	90	90	90	75	60	60	65	55	55	50
E. 60° N.....	.....	.....	40	45	45	45	40	35	45	45	40
N.....	.....	.....	40	40	45	45	40	40	35	35	35
N. 30° W.....	45	50	55	50	50	55	55	50	45	35	30
N. 60° W.....	65	40	35	35	30	25	25	30	30	30	35
W.....	65	60	60	50	45	40	40	35	30	40	45
W. 30° S.....	55	40	35	30	25	15	30	20	25	30	45
W. 60° S.....	45	45	45	45	50	55	55	50	50	45	45

TABLE 80. — *The temperatures for March 16, 1876, in degrees Fahrenheit.*

	30.00	29.90	29.80	29.70	29.60	29.50	29.40	29.30	29.20	29.10	29.00
S.....	78	74	59	60	47	40	42	40	40	38	.....
S. 30° E.....	74	70	70	67	67	58	51	52	52	48	.....
S. 60° E.....	64	64	64	62	63	52	44	50	52	51	.....
E.....	40	40	38	34	38	36	35	38	38	40	.....
E. 30° N.....	18	15	10	12	16	18	24	32	33	34	.....
E. 60° N.....	0	3	9	11	14	16	20	19	30	30	.....
N.....	—2	5	10	12	11	16	18	19	20	24	.....
N. 30° W.....	10	12	12	14	16	19	20	20	27	26	.....
N. 60° W.....	9	12	14	16	18	20	22	24	26	28	.....
W.....	20	16	20	19	21	23	24	26	26	30	.....
W. 30° S.....	42	33	30	27	32	30	29	30	30	32	.....
W. 60° S.....	53	47	44	40	40	36	24	36	35	36	.....

The negative sign for the angle i means that the vectors are directed inward relative to the isobars, or in other words the radial velocity has the negative sign, — u .

In Table 81 the data for the nine selected cyclones are given for a mean or composite cyclone. The data were extracted from the original charts, as in Tables 78, 79, and 80, and the means taken at each point of intersection of the radii and the isobars. The variations of the elements can be readily studied by inspection. In Table 81, I, the mean wind velocity for each isobar is taken, this giving data for a uniform or perfect cyclone from which all the irregularities of the circulation have been eliminated. These have been transformed into velocities in meters per second by the factor 0.447. In Table 81, II, the interior angle — i is seen to vary considerably from point to point, but the mean values for each isobar are taken, and they prove to be nearly constant, about 44° , except on the inner isobar, where it diminishes to 40° . If the cyclone were a true dumb-bell vortex, it would be easy to construct the entire system from these data, assuming the height of the plane to be taken as the asymptote. It will not, however, be profitable to proceed on this supposition. With the values of η and — i the corresponding velocities — u (radial) and + v (tangential) have been computed. Finally, these values were interpolated for the corresponding isobars, 760, 755, 750, 745, 740, 735 millimeters, and the discussion will be generally transformed into the metric system. In Table 81, III, the temperatures in degrees Fahrenheit are collected together, and they range from 11.3° F. to 70.7° F. In all cases of the velocity, angle, and temperature, the points corresponding with the first collection of the data were plotted and average curves were drawn thru

the points. The values which appear in Table 81 are thus somewhat smoothed, but no essential differences occur. The slope and the curvature of these lines form a subject of much interest and they are very instructive.

TABLE 81. — *The mean wind velocities, angle i , and temperatures derived from nine typical cyclones central near the Ohio Valley.*

I. ADJUSTED WIND VELOCITIES, IN MILES PER HOUR.

B (inches). B (mm.)	30.00	29.90	29.80	29.70	29.60	29.50	29.40	29.30	29.20	29.10	29.00
	762.0	759.5	756.9	754.4	751.8	749.3	746.8	744.2	741.7	739.1	736.6
S.....	14.2	14.4	14.9	16.7	20.0	23.3	25.6	27.0	28.0	28.2	28.0
S. 30° E.....	12.3	13.8	15.7	17.5	19.2	20.8	22.4	23.4	24.0	24.2	24.4
S. 60° E.....	14.0	15.2	16.4	17.7	18.7	19.7	20.6	21.3	22.0	22.4	22.6
E.....	14.0	15.8	17.0	17.0	16.4	16.0	15.3	15.2	15.7	16.8	18.0
E. 30° N.....	16.8	17.8	18.0	18.3	18.8	19.2	19.0	18.1	17.6	17.7	18.2
E. 60° N.....	17.0	17.6	17.3	17.1	17.2	17.5	17.7	17.8	17.6	17.4	17.0
N.....	14.0	14.6	15.3	16.5	18.4	21.0	23.8	25.4	25.4	24.7	22.2
N. 30° W.....	13.7	15.0	17.3	20.0	22.6	24.7	25.9	25.8	24.4	22.5	22.0
N. 60° W.....	16.4	18.6	21.0	23.2	24.4	24.7	24.8	24.4	23.6	23.1	23.0
W.....	17.0	20.8	23.2	24.4	25.3	25.8	26.0	25.6	25.2	25.4	25.7
W. 30° S.....	14.0	15.6	17.4	19.1	20.7	22.5	23.7	24.4	24.8	24.8	25.0
W. 60° S.....	12.5	15.6	19.2	21.5	23.2	24.4	25.0	25.0	25.0	24.7	24.3
Means.....	14.7	16.2	17.7	18.8	20.4	21.6	22.5	22.8	22.8	22.6	22.5
η	6.6	7.2	7.9	8.4	9.1	9.6	10.1	10.2	10.2	10.1	10.0

II. — i = ANGLE OF THE WIND WITH THE ISOBAR.

	30.00	29.90	29.80	29.70	29.60	29.50	29.40	29.30	29.20	29.10	29.00
S.....	47.8	46.4	45.3	44.2	43.7	43.0	42.6	43.3	44.0	44.8	45.8
S. 30° E.....	44.0	43.0	45.8	46.0	46.0	45.7	45.2	44.0	42.6	40.5	38.5
S. 60° E.....	34.6	37.2	39.2	41.3	43.5	44.6	44.7	44.8	41.5	38.0	35.3
E.....	39.0	40.5	41.6	42.5	43.0	42.7	41.8	40.7	39.6	38.4	37.5
E. 30° N.....	40.0	42.0	44.0	45.4	46.2	46.2	46.0	45.8	45.5	45.0	45.0
E. 60° N.....	27.5	29.0	32.4	35.8	39.0	42.0	45.8	44.0	43.6	42.0	40.4
N.....	53.3	53.8	54.0	54.0	54.0	54.0	53.7	52.8	51.4	49.8	48.0
N. 30° W.....	56.0	54.6	53.0	51.2	49.5	47.8	46.0	44.2	42.8	41.5	40.3
N. 60° W.....	50.2	48.7	47.4	45.5	44.0	42.6	41.5	40.2	39.3	38.3	38.0
W.....	44.4	43.3	41.6	40.0	38.5	37.2	35.8	34.7	33.8	32.8	32.0
W. 30° S.....	40.0	38.4	37.3	36.2	35.0	34.4	34.2	34.0	34.0	34.0	34.0
W. 60° S.....	50.5	51.2	51.4	51.6	51.8	52.0	51.0	49.2	46.4	43.8	40.5
Mean — i	43.9	44.2	44.4	44.5	44.5	44.4	43.9	43.1	42.0	40.7	39.6
— u	—4.5	—4.9	—5.4	—5.7	—6.2	—6.5	—6.9	—7.0	—7.0	—6.9	—6.8
+ v	4.8	5.3	5.8	6.1	6.7	7.0	7.4	7.5	7.5	7.1	7.3
B (mm.).....	760.0	755.0	750.0	745.0	740.0	735.0	730.0	725.0	720.0	715.0	710.0
— u	—4.9	—5.6	—6.4	—7.0	—7.5	—8.0	—8.5	—8.9	—9.3	—9.6	—9.9
+ v	5.2	5.7	6.0	6.9	7.5	8.0	8.5	8.9	9.3	9.6	9.9

III. TEMPERATURES, IN DEGREES FAHRENHEIT.

	30.00	29.90	29.80	29.70	29.60	29.50	29.40	29.30	29.20	29.10	29.00
S.....	67.2	63.0	59.5	56.6	54.6	52.9	51.2	49.8	48.7	47.7	47.0
S. 30° E.....	70.7	68.3	66.2	64.0	62.0	60.0	58.0	56.3	54.7	53.2	52.0
S. 60° E.....	65.2	63.5	62.0	60.6	59.3	58.0	56.8	55.7	54.6	53.8	53.0
E.....	48.7	47.6	47.4	48.0	49.8	50.4	50.8	49.9	49.3	48.7	48.0
E. 30° N.....	30.0	30.9	32.5	34.6	37.0	39.9	40.4	41.6	43.0	44.0	45.0
E. 60° N.....	19.0	21.9	25.5	28.4	31.4	34.1	36.8	38.8	41.0	43.2	45.0
N.....	11.3	14.6	17.8	20.7	23.4	26.2	29.4	32.4	35.2	38.0	41.0
N. 30° W.....	12.2	14.4	16.7	19.4	22.0	24.9	28.0	31.0	34.0	37.7	41.0
N. 60° W.....	15.6	17.4	19.3	20.9	22.6	24.3	26.2	28.6	31.9	35.7	40.0
W.....	19.5	20.5	21.9	23.5	25.3	27.7	30.2	33.0	36.2	39.6	44.0
W. 30° S.....	31.2	31.4	31.8	32.2	33.1	34.1	35.4	35.9	39.0	41.4	44.3
W. 60° S.....	46.9	46.0	45.0	44.3	43.8	43.6	43.8	44.0	44.7	45.4	46.4

We next interpolated all the values of η , — i , and t in the English system to the corresponding values in the metric system, and plotted them on diagrams constructed from the isobar distances given in Table 77.

B	η
760	1250000
755	975000
750	733000
745	508000
740	300000
735	110000

These diagrams are not reproduced. Returning to the original charts of the nine selected cyclones, the mean temperatures in a north-and-south line thru the central region

were carefully computed, giving the adopted mean values of the temperature in latitude for this region, the normal isobars running nearly east and west in this part of the United States.

TABLE 82.—Mean temperatures thru the center from north to south.

B.		°C.
Mm.		°
760	N.	- 3.2
755	N.	- 6.5
750	N.	- 3.8
745	N.	- 1.2
740	N.	+ 1.2
735	N.	3.5
732.5		5.0
735	S.	6.4
740	S.	8.7
745	S.	11.0
750	S.	13.6
755	S.	16.3
760	S.	19.1

These temperatures were carefully compiled from point to point in latitude, and embrace the set of temperatures in longitude covered by the cyclone, so that they become the normals for this group of cyclones from which the variations are to be computed. The temperatures in Table 81, III, were turned into centigrade degrees, and then they were interpolated from the system of isobars in inches to the adopted system of isobars in millimeters. From these, on the respective parallels, the normal temperature is to be subtracted to obtain the temperature residuals or variations which distinguish a cyclone from the temperatures belonging to the same area, if it were undisturbed by any local circulations.

TABLE 83.—The variation of temperature (°C.), wind velocity (m./sec.), and the angle α in a mean cyclone of the United States.I. Δ . TEMPERATURE VARIATIONS, CENTIGRADE.

Radius.	α	α 20° E.	α 40° E.	α 60° E.	α 80° E.	α 100° E.	α 120° E.	α 140° E.	α 160° E.	α 180° E.	α 200° E.	α 220° E.	α 240° E.	α 260° E.	α 280° E.	α 300° E.
760	-1.3	+1.3	+2.9	+2.1	+1.7	+2.2	0.0	-1.1	-3.2	-6.4	-7.1	-5.6				
755	-1.5	+1.7	+2.8	+2.1	+1.8	+2.3	+0.1	-1.2	-3.0	-5.5	-6.1	-4.6				
750	-1.1	+1.9	+2.9	+2.8	+1.7	+2.1	+0.1	-1.0	-2.8	-4.3	-4.7	-3.3				
745	-0.5	+1.4	+2.9	+2.8	+1.7	+1.8	+0.7	-0.4	2.4	-2.7	-3.3	-2.1				
740	+0.2	+2.3	+3.0	+2.4	+1.2	+1.6	+0.8	+0.4	-1.9	-0.7	-1.1	-0.4				
735	+0.9	+2.7	+3.2	+2.1	+1.0	+1.1	+1.3	+1.3	+0.8	+1.7	+1.0	+1.1				

II. q . WIND VELOCITIES IN METERS PER SECOND.

Radius.	q	q 20° E.	q 40° E.	q 60° E.	q 80° E.	q 100° E.	q 120° E.	q 140° E.	q 160° E.	q 180° E.	q 200° E.	q 220° E.	q 240° E.	q 260° E.	q 280° E.	q 300° E.
760	6.4	6.0	6.7	6.9	7.9	7.8	6.5	6.6	8.1	8.9	6.8	6.7				
755	7.3	7.6	7.8	7.6	8.1	7.6	7.3	8.7	10.2	10.8	8.4	9.4				
750	10.0	9.1	8.7	7.2	8.5	7.8	9.0	10.8	11.0	11.4	9.8	10.7				
745	11.9	10.3	9.4	6.8	8.2	8.0	11.1	11.6	11.0	11.5	10.8	11.2				
740	12.6	10.8	9.9	7.3	7.9	7.8	10.9	10.4	10.4	11.3	11.1	11.1				
735	12.6	11.0	10.1	8.5	8.2	7.6	9.3	9.6	10.2	11.5	11.2	10.7				

III. α . THE ANGLE WITH THE ISOBAR.

Radius.	α	α 20° E.	α 40° E.	α 60° E.	α 80° E.	α 100° E.	α 120° E.	α 140° E.	α 160° E.	α 180° E.	α 200° E.	α 220° E.	α 240° E.	α 260° E.	α 280° E.	α 300° E.
760	47	45	37	40	42	29	54	55	49	44	39	51				
755	44	46	41	42	45	35	54	51	46	40	36	51				
750	43	46	44	43	46	41	54	48	43	38	35	52				
745	43	44	45	41	46	44	53	45	41	35	34	50				
740	44	41	39	39	45	43	50	42	39	33	34	45				
735	46	38	35	37	45	40	47	39	38	31	31	39				

The data of Table 83 are transferred to fig. 18, which presents a circular cyclone equivalent to those selected on the charts. Lines are drawn thru the points of equal temperature disturbances. The 0 disturbance is on a line nearly north and

south thru the center, the greatest cold is on the southwest edge of the 760 isobar and the warmest area covers the southeast quadrant. On comparing fig. 18 with MONTHLY WEATHER REVIEW, February, 1906, 34, figs. 5 to 10, it is seen that they are in harmony. It is evident that similar careful computations of the temperature distributions should be made on every 1,000-meter level, and it is inferred that the asymmetrical arrangement found in the discussion of 1906 will be substantially confirmed in all the levels, tho of course the details will be greatly improved. The concentration of the cold area in the cyclone is more pronounced than is that of the warm area, which is spread quite uniformly over the eastern sectors, but there is no tendency for one system to intrude upon the other, and the evidence is decisive that there is no warm-centered cyclone in the lower levels of the United States.

The wind vectors call for no special comment except that in the process of composition, whereby the elongated or elliptical isobars are rendered circular, the two independent streams of warm and cold air, respectively, are obscured except for the cold and warm areas that have been described. In the individual cyclones it is easy to see that the cold current tends to overrun the warm currents, and this is shown in part by the fact that the vectors of the cold current are nearly at right angles to the vectors of the warm current in the south to south-east quadrant. This same condition is also shown in the northern quadrant where the warm current tends to overrun the cold current, tho this is more confused by the interaction with the eastward drift and the composition of forces taking effect over the barometric "saddle" in that region. In the southern quadrant the motions of the cyclone and the eastward drift are generally in about the same direction, northeastward for both currents, while in the northern quadrant they are counter directed and the relative changes in direction are pronounced.

THE COMPONENT VELOCITIES IN THE HIGHER LEVELS.

The campaign during the international cloud year 1896-97 was conducted on the part of the Weather Bureau with the special object of determining as accurately as possible the radial (u_r) and tangential (v_t) components of the velocity in cyclones and anticyclones proper, as distinguished from the meridional (u_m) and the longitudinal (v_l) components of the velocity due to the circulation in the general vortex of the hemisphere taken by itself. A very large number of observations were available, more than 6,000, and special care was taken to separate these components as thoroly as possible. It is evident that the data employed were derived from all sorts of circulations, such as occurred in that year, and that it would not have been possible to sort it out in such a way as to separate that belonging to *strongly* developed cyclones and that pertaining to an aimless form of the circulation. It is evident that our computations should properly be limited to include only firmly formed cyclonic circulations, if it were possible to do so. On this account the derived components (u_r , v_t) are not very reliable as to details in all the levels, and they need to be supplemented by numerous observations extending over many years. The discussion of the Weather Bureau data can be found in Chapters 6 and 7 of the Cloud Report, and some further remarks upon its significance occur in Chapter 11. Our special concern at this time is with the summary of the data in Table 126, page 626, which will be the basis of the following considerations.

It will be noted that we are dealing with the same system of radial distribution, as may be seen by comparing Table 77 of this paper with the radial distances I, II, III, of the Cloud Report, Table 126.

Table 126.	Table 77.
III. 1250000	760 1250000
II. 750000	750 733000
I. 250000	740 300000

It is evident that by plotting the three points given in

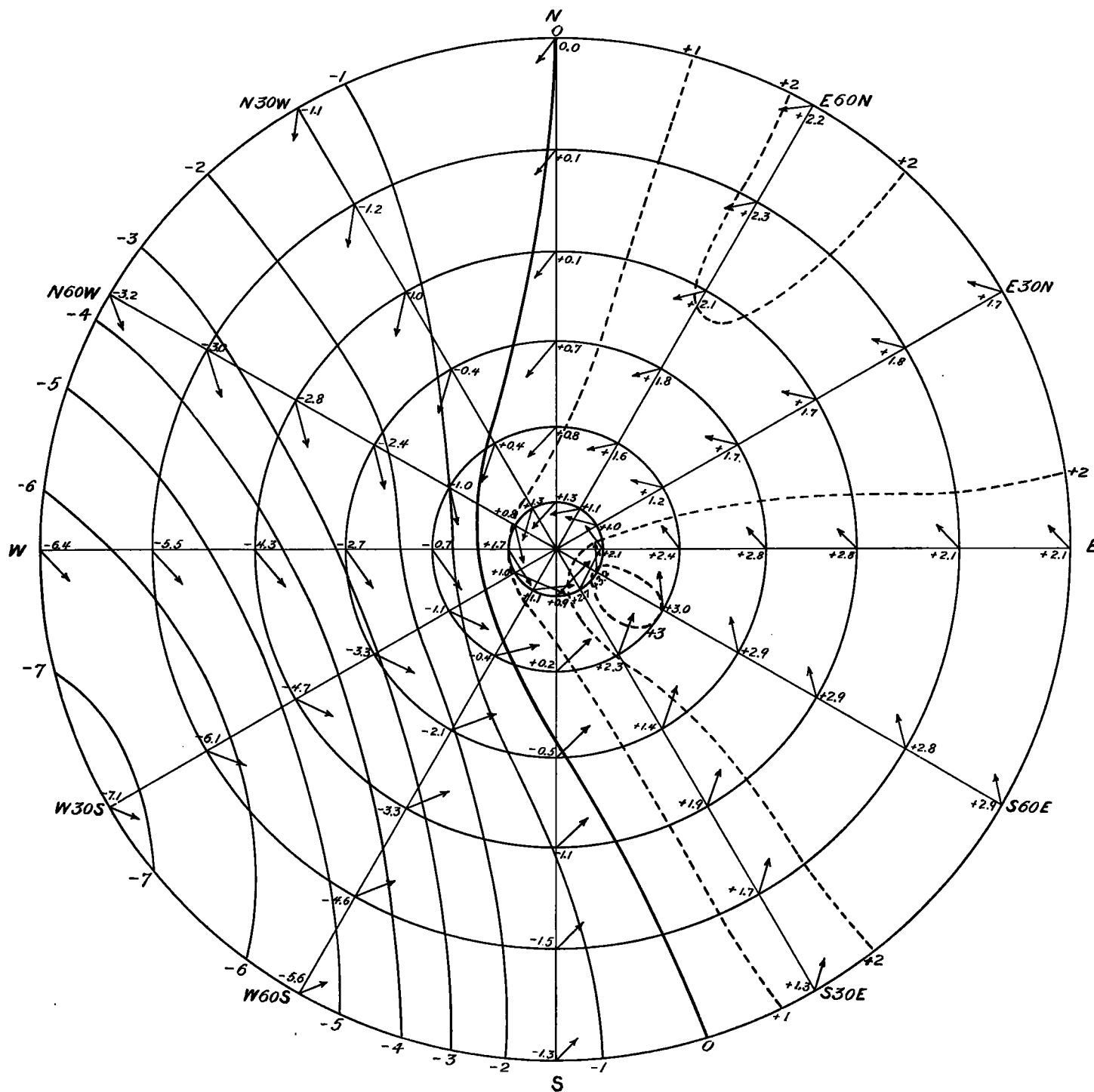


FIG. 18.—Land cyclone having circular isobars equivalent to the elongated cyclone of the United States, with the temperature distribution and the wind vectors, the center being located in the Ohio Valley. Compare the weather map, March 6, 1908.

Cloud Report, Table 126, for the u , and v , components on each level there will be no difficulty in constructing diagrams which determine approximately the average values of these components in a normal system. Attention has been paid to placing the values of u , v , from Table 81, II, at the basis of this cyclonic system and enlarging the values u , v , derived from the diagrams because they are doubtless smaller than should prevail in highly-developed vortices, as already explained. It has been found necessary to rectify the v component only a little in the several levels. The u component is much more difficult to secure from direct observations, and it is less reliable, so that the modifications are greater. What are supposed to be the most probable values of the u components have been ex-

tracted from the diagrams for use in the following computations. Table 84, I and II, contain these adopted values of the u component and v component corresponding with the lines commencing on the 5-millimeter-spaced isobars of 760 to 735. It was stated in the Cloud Report that the values of u , v , there deduced were in the proper form for use in the equations of motion. It has been already pointed out that the u , component in the upper levels is of the same sign as in the lower levels, thus differing from the usual supposition made regarding this component which assumes that the radial component in the high strata should be directed outwards, as is common in the dumb-bell-shaped vortex.

TABLE 84.—The observed radial (u) and tangential (v) components of the velocity derived from Table 126 of the Cloud Report.I. u —THE OBSERVED RADIAL VELOCITIES.

Height.	1250000 (1) 760	975000 (2) 755	733000 (3) 750	508000 (4) 745	300000 (5) 740	80000 (6) 735
Meters.						
10,000	— 0.5	— 0.7	— 1.0	— 1.3	— 1.6	— 2.0
9,000	— 1.5	— 2.1	— 2.7	— 3.0	— 3.7	— 4.5
8,000	— 2.0	— 3.0	— 4.0	— 4.5	— 5.5	— 6.0
7,000	— 3.0	— 4.0	— 5.0	— 6.0	— 7.0	— 7.5
6,000	— 3.0	— 4.0	— 5.0	— 6.0	— 7.0	— 8.0
5,000	— 2.5	— 3.0	— 4.0	— 4.5	— 6.0	— 7.0
4,000	— 2.0	— 2.5	— 3.0	— 4.0	— 5.0	— 6.0
3,000	— 2.0	— 2.0	— 2.0	— 2.5	— 3.5	— 4.5
2,000	— 2.0	— 2.0	— 2.0	— 2.0	— 2.0	— 2.0
1,000	— 3.5	— 3.5	— 4.0	— 4.0	— 4.0	— 4.0
000	— 4.5	— 5.0	— 6.0	— 6.5	— 6.5	— 6.0

II. v —THE OBSERVED TANGENTIAL VELOCITIES.

Height.	(1)	(2)	(3)	(4)	(5)	(6)
Meters.						
10,000	+ 2.0	+ 2.5	+ 3.0	+ 4.0	+ 4.5	+ 5.0
9,000	+ 4.0	+ 6.0	+ 8.0	+ 8.5	+ 8.5	+ 9.0
8,000	+ 4.0	+ 7.0	+10.0	+12.0	+12.0	+11.0
7,000	+ 5.0	+10.0	+13.0	+14.0	+14.0	+14.0
6,000	+ 6.0	+11.0	+14.0	+15.0	+15.0	+16.0
5,000	+ 7.0	+12.0	+15.0	+16.0	+18.0	+19.0
4,000	+ 7.0	+11.0	+14.0	+17.0	+19.0	+21.0
3,000	+ 6.0	+10.0	+13.0	+16.0	+19.0	+23.0
2,000	+ 5.0	+ 9.0	+12.0	+15.0	+18.0	+22.0
1,000	+ 5.0	+ 6.0	+ 8.0	+10.0	+12.0	+14.0
000	+ 5.0	+ 5.5	+ 6.0	+ 6.0	+ 6.5	+ 7.0

III. THE COMPUTED ANGLE $-i$, $\tan(-i) = \frac{-u}{v}$.

Height.	(1)	(2)	(3)	(4)	(5)	(6)	Mean.	az .
Meters.								
10,000	—14 02	—15 39	—18 26	—18 00	—19 34	—21 48	—18.0	72.0
9,000	—20 33	—19 17	—18 39	—19 23	—23 31	—26 34	—20.3	69.7
8,000	—26 34	—23 12	—21 48	—20 33	—24 37	—28 37	—24.2	65.8
7,000	—30 58	—21 48	—21 02	—23 12	—26 34	—28 11	—25.3	64.7
6,000	—26 34	—19 59	—19 39	—21 48	—25 01	—26 34	—23.3	66.7
5,000	—19 39	—14 02	—14 56	—15 43	—18 26	—20 14	—17.2	72.8
4,000	—15 57	—12 48	—12 06	—13 14	—14 45	—15 57	—14.1	75.9
3,000	—18 26	—11 19	— 8 45	— 8 53	—10 26	—11 04	—11.5	78.5
2,000	—21 48	—12 32	— 9 28	— 7 36	— 6 20	— 5 12	—10.5	79.5
1,000	—34 53	—30 15	—26 34	—21 48	—18 26	—15 57	—24.7	65.3
000	—41 59	—42 16	—45 00	—47 17	—45 00	—40 36	—45.5	44.5

Table 84, I, contains the radial velocities, u , as derived from the cloud observations of 1896–97, Section II, the corresponding tangential velocities v , and Section III, the angle $-i$, direction inward at all points. The vortical characteristics of the tangential velocities appear most distinctly on the 2,000 to 4,000-meter levels, but it is very evident that these velocities do not conform to the dumb-bell-shaped vortex in any satisfactory manner. This is also seen in the values of the angle $-i$, which begin at -45° at the surface, decrease to -11° at 3,000 meters, rise to -25° at the 7,000-meter level and fall to -18° at the 10,000-meter level. The inward angle at the bottom of the vortex is not converted into an outward angle in the upper part of the vortex, but there is an inflow at all

levels, most vigorous at the surface, least at the 3,000-meter level and passing thru another maximum at the 7,000-meter level. The values of $az = 90^\circ - i$ go thru the counterpart values.

TABLE 85.—The computed values of aA .

$$aA = \frac{v}{\sigma \sin az} = \frac{-u}{\sigma \cos az}$$

Height.	1250000 (1) 760	975000 (2) 755	733000 (3) 750	508000 (4) 745	300000 (5) 740	80000 (6) 735
Meters.						
10000	165	266	431	828	1593	6732
9000	342	652	1152	1775	3091	12577
8000	353	781	1469	2523	4401	15659
7000	467	1105	1900	2998	5217	19852
6000	537	1201	2028	3180	5518	24801
5000	595	1269	2118	3270	6325	25306
4000	535	1157	1953	3439	6348	27298
3000	506	1046	1794	3187	6441	29300
2000	431	946	1659	2978	6040	27598
1000	488	713	1220	2120	4216	18198
000	538	762	1158	1741	3064	11524

The unit = 0.000 000 01 = 1×10^{-8} THE COMPUTED VORTEX LINES aA .

In order to obtain further information regarding the structure of this cyclonic circulation, we derive from the formulas of the dumb-bell-shaped vortex,

$$aA = \frac{v}{\sigma \sin az} = \frac{-u}{\sigma \cos az}$$

We can proceed to compute the velocities from the terms a , A , σ , and az , if these are known, or we can compute aA from v , u , σ , and az , if these are available. In Tables 77 and 84 all the latter data are to be found, and from them the values of aA are computed. This work has been performed and the results are given in Table 85. It does not appear from the values of az in Table 81, III, that a can be taken out as a constant, so no attempt is made to separate the terms in aA . The maxima in the middle levels occur higher up in the outer than they do in the inner parts, and the values of aA are very much greater near the axis. If these values of aA are plotted on a diagram and lines are drawn thru the equal values of aA , taking as the initial values those occurring at the surface on the adopted lines (1), (2), (3), (4), (5), (6), we shall have a system like that in fig. 19. This is a remarkably suggestive structure and will require much careful consideration. The curvature is concave toward the axis, instead of convex as in the hurricane and tornado, the lines are crowded together in the outer rather than in the inner parts of the vortex. In these respects the system is quite the reverse of the ordinary dumb-bell vortex and suggests for the aA lines a current function,

$$\psi = A \sigma^2 \cos az,$$

rather than that adopted for the tornado,

$$\psi = A \sigma^2 \sin az,$$

both satisfying the differential equation (23).

If fig. 19 is turned upside down and the axis is transferred to the right-hand side of the lines, the structure resembles a dumb-bell vortex. The concentration is at a distance from the axis rather than near it, and the lines are farther apart as the axis is approached in the observed cyclone. At the surface and up to 2,000 meters there is a small departure from the geometrical system, so that evidently the spacing of the lines as given by the isobar system on the weather charts is not in conformity on the outer lines (1), (2), to the remainder

of the structure. If we could imagine the cyclone to be surrounded by a cylinder, and the wall of the cylinder to act as an axis, then the computation would proceed as in the case of a central axis, so far as the spacing of these lines is concerned.

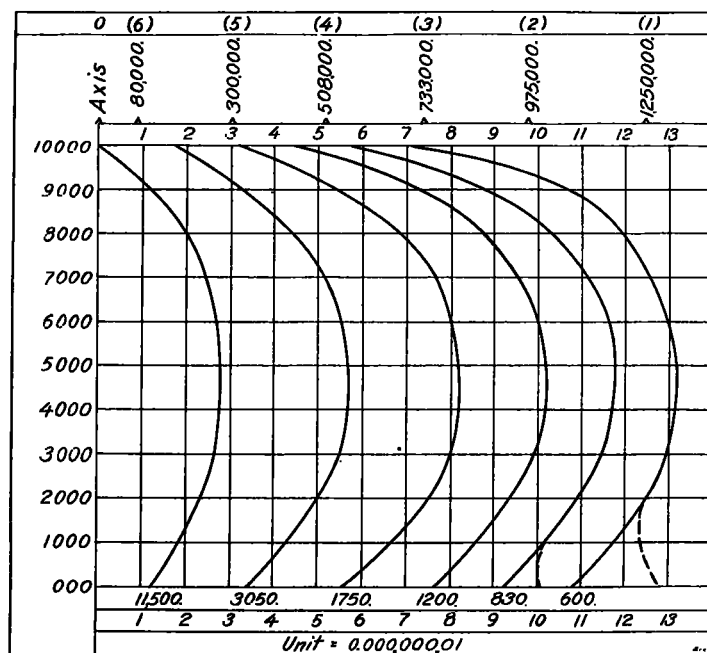


FIG. 19.—The computed vortex lines $a\Delta$ of the asymmetric land cyclone.

THE CONCAVE DUMB-BELL-SHAPED VORTEX.

The preceding discussion of the vortex lines, which involved the computation of the product of two constants a and Δ , a being about 0.10 and Δ being a constant on each vortex line but having different values on the different lines, has resulted in a vortex system which suggests a convex dumb-bell-shaped vortex, where the lines are concave toward the axis instead of convex, as in the tornado and the hurricane. These two vortices satisfy the equations of motion as follows:

	Convex vortex.	Concave vortex.
Current function,	$\psi = A\omega^2 \sin az.$	$\psi = A\omega^2 \cos az.$
Radial velocity,	$u = -Aa\omega \cos az.$	$u = +Aa\omega \sin az.$
Tangential velocity,	$v = +Aa\omega \sin az.$	$v = +Aa\omega \cos az.$
Vertical velocity,	$w = +2A \sin az.$	$w = +2A \cos az.$

It is easy to trace out the relative differences by simply interpreting the trigonometrical signs. In the concave vortex the radial velocity is zero for $az = 0^\circ$, increases outward to $az = 90^\circ$, and returns to zero for $az = 0^\circ$. The tangential velocity begins at a maximum for $az = 0^\circ$, decreases to zero for $az = 90^\circ$, and increases again to the maximum. The vertical velocity begins at a maximum for $az = 0^\circ$, decreases to zero for $az = 90^\circ$, and then increases to a maximum; v and w reverse direction at $az = 90^\circ$. Whether this is a possible vortex in the atmosphere is a question which does not need to be considered in this connection for the following reasons. When one attempts to match the observed angles i of Table 84 III with the lines of fig. 19, as was done by some computations, it is readily seen that they do not in anywise agree in meeting the required conditions of the suggested concave vortex, and we must conclude that the suggested analogy is in fact fictitious and not very useful.

What we actually have in the cyclone is a convex dumb-bell-shaped vortex disturbed from normal conditions, and distorted almost beyond recognition by two fundamental circumstances. The first is that the temperature distribution is entirely changed. In the hurricane the temperatures are stratified horizontally, but in the cyclone they are separated vertically, the warm and cold masses

lying side by side, and the streams seeking to interpenetrate horizontally in the different levels by the action of gravitation. The second is the fact that the imperfect dumb-bell-shaped vortex which results from the preceding process attempts to lift its head into the rapidly flowing eastward drift which keeps stripping off the top layers and thus prevents the formation of the vortex in its natural proportions. This process has been fully described in the MONTHLY WEATHER REVIEW, February, 1903, 31, fig. 28, where the scheme of the isobars and wind vectors is developed. I therefore interpret fig. 19, above, to mean that it represents a convex dumb-bell-shaped vortex struggling to establish equilibrium between masses of different temperatures on the same levels, while the top layers are continuously stripped away in the eastward drift. The inward radial velocity which properly belongs to the lower sections of a perfect dumb-bell-shaped vortex continues to prevail as long as there is any tangential velocity surviving, because the lower half of the dumb-bell-shaped vortex is in fact never completed in this cyclonic circulation. It is really a nameless survival of this typical vortex, and is a succession of hydrodynamic circulations more due to mutual reactions of warm and cold streams on the same horizontal plane, than to any total vortex structure involving mutual dependencies thru great depths. It is a question whether these cyclonic circulations can ever be analyzed as a vortex structure of any given type, as has always been assumed to be the case in the general discussions which prevail in meteorological literature. Certainly there is no prospect of settling this problem until such accurate discussions of the observations of temperature, pressure, and wind vectors become available in all the levels as are given for the surface in fig. 18 of this paper.

As a matter of fact it is exceedingly difficult to secure the correct values of the radial velocity u in the upper levels, as is abundantly testified by the work in the Cloud Report of 1896-97. In that place the motions of all sorts of cyclones, large and small, whether fully or incompletely developed, were united in one composite. Evidently for the study of this vortex problem in the upper levels only the strong cyclones should be used so that the data on the upper levels may be comparable with the data of fig. 18. In case the velocities of the Cloud Report, Table 126, adopted to extend the discussion above the surface, are not representatively correct the conclusions of this paper must be modified, but it is certain that no superficial treatment of the data of cyclones and anticyclones in the upper levels suffices to form the basis of our theoretical discussion. The cyclonic components u , v , must be fully separated from the eastward drift u , v , in all the levels, and a continuous campaign of observations with nephoscopes and theodolites, extending over several years, seems to be demanded by this branch of meteorological science.

DRY FARMING.

The expression "dry farming" has come into prominence during the last three years, and the "Third Trans-Missouri Dry-farming Congress," held at Cheyenne, Wyo., February 23-25, 1909, was the occasion of an enthusiastic presentation of the methods and the success attaching to this new departure. The term "dry farming" itself may be considered as an abbreviation of the expression "dry-land farming." The general idea of the method consists in giving up the attempt to raise a crop every year continuously on a given piece of land, and attempting instead of that to so conserve and utilize the moisture that the land receives from rain and snow as to secure a crop once every two or three years.

Few persons realize that the great success of the pioneers in a semiarid country depended upon their having the accumulated moisture stored up in the soil for many years upon which the first crops could feed. After a few years this accumulation is reduced below the ability of the annual precipitation to meet the demand made upon it, and either artificial irriga-